AUG 25 1966

National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-9299

USS-10

ST - COMA - PF - 10509

SOLAR WIND FLOW PAST COMETS
I I

by

Z. M. Ioffe

(USSR)

FACILITY FORM 602

N66-87931
(ACCESSION NUMBER)

7
(PAGES)

CR 79784
(NASA CR OR TMX OR AD NUMBER)

(THRU)

none
(CODE)

(CATEGORY)

24 AUGUST 1966

SOLAR WIND FLOW PAST COMETS *

II

Astronomicheskiy zhurnal,
Tom 43, No. 3, 655-658,
Izdatel'stvo "NAUKA," 1966

by Z. M. Ioffe

SUMMARY

The comet is considered as a source in supersonic flow. The problem is stated about supersonic compressible gas stationary flow past a subsonic source. It is shown that at infinity the interface between the source's and the flow's media approaches the cylinder.

The minimum radius r_{min} of the source is found which characterizes the ionization region. The parameters in the neighborhood of the sphere of the radius r_{min} are determined from the asymptotic values of thermodynamic parameters.

*

* *

In the work rf [1], available as ST - COMA - PF - 10466 of 28 March 1966, the comet is considered as a source placed in supersonic stationary flow. The contour of plasma head is found under the following assumptions: the pressure on the interface between the source's and the flow's media is given by the Newton formula; the medium is assumed incompressible and the problem resolved is a plane one.

Below we shall state the problem of supersonic stationary flow of a compressible gas past a subsonic source and consider some of the preliminary results.

The compressible gas flow's source cannot be extended inside a

---

* OBTEKANIYE KOMETY SOLNEČHNYM VETROM

sphere of some radius r_{min} [2] that is, the minimum radius of the "source's zone," or region where processes leading to the emergence of the source take place. We shall consider that the streamline flow does not distort the sphere of radius r_{min} and does not disrupt the spherical symmetry of the flow in its vicinity. Then, as will be shown below, we shall be able to find r_{min}, the thermodynamic parameters and the radial velocity on the surface of the sphere. By the strength of the above assumptions, the other velocity components are zero.

If the source, placed in the flow, has sufficient power, there will exist two surfaces, the shock wave (α) and the interface between the two media (β), dividing the entire field flow into three regions (Fig. 1): 1 is the unperturbed flow, 2 is the flow after passage of the shock wave (outer flow), 3 is the gas of the source (inner flow).

As pointed out in [1], the problem of flow past the source is in many traits analogous with the problem of flow past a blunt body; this is why we may utilize for its solution the method developed by Belotserkovskiy [3]. However, some of the properties of the surface β and of the flow in the region 3 may be ascertained without resolving the whole problem. The flow in the region 2 will be completely analogous to the flow behind an outgone shock wave setting in at flow past a blunt body.

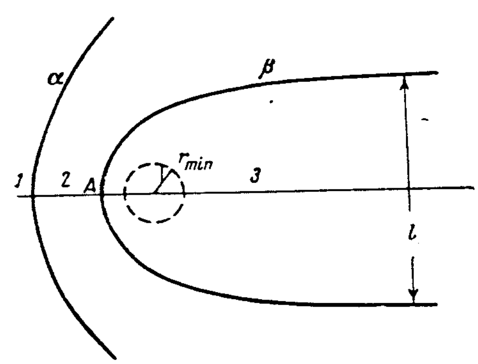

Fig. 1

It follows from the spherical symmetry of the flow in the neighborhood of the sphere r_{min} that in the region 3 the flow is potential and the entropy function φ [3] is constant in the entire region.

Let us introduce the dimensionless variables, referring the velocity to the velocity maximum v_{max}, the density and the pressure respectively to the values ρ_0 and $\rho_0 v^2_{max} \cdot \rho_0$, that is, the density at the point $v = 0$. The Bernoulli equation in dimensionless form will be written [3]:

$$\bar{p} = \frac{\gamma - 1}{2\gamma}(1 - \bar{v}^2)\bar{\rho},$$

where $\bar{p}$, $\bar{v}$ and $\bar{\rho}$ are respectively the dimensionless pressure, velocity and density. From this equation and the entropy function $\varphi = \bar{p}/\bar{\rho}^{\gamma}$ we may express the pressure as a function of $\bar{v}$ and φ.

(1)

But in the inner flow $\varphi = \text{const}$ and it follows from (1) that at $\bar{v} = \text{const}$, $\bar{p} = \text{const}$.

Tables have been compiled in the Computing Center of the USSR Academy of Sciences for the supersonic flow of a perfect gas past blunt cones at zero angle of attack [4]. It may be seen from these tables that the pressure on a streamlined cone approaches a constant value as its summit drifts away; this value depends only on the parameters of the incident flow and on the cone's aperture angle. For a cylinder (aperture angle is zero) the pressure at infinity does not depend on the diameter of the cylinder and on the shape of the bluntness. Comparing these data with formula (1), we see that surface may asymptotically approach the cylinder, but not the cone, for in the latter case the pressure in the inner flow must vary continually.

For a cylinder the asymptotic value of dimensionless pressure, referred to $\rho_f c_*^2$ (ρ_f being the density of the unperturbed flow, c_* the critical speed of sound), is equal to 0.096 for a Mach number $M = 6$ and 0.033 for $M = 10$ [4]. For the solar wind, p_f is equal to about $0.8 \cdot 10^{-23}$ g/cm^3 ($n_f = 5$ cm^{-3}), the pressure is 10^{-10} dyne/cm^2, the magnetic field H is $5 \cdot 10^{-5}$ gauss. At $v_f = 3 \cdot 10^7$ cm/sec $M = 6$ and at $v_f = 5 \cdot 10^7$ cm/sec, $M = 10$. At such parameters, the asymptotic value of pressure on the flown about cylinder is $2.5 \cdot 10^{-10}$ dyne/cm^2 for $M = 6$ and $2.3 \cdot 10^{-10}$ dyne/cm^2 for $M = 10$. As was to be expected, the pressure is little dependent on the Mach number.

Now the problem of hypersonic flow past a subsonic source can be formulated. We must know the radius r_a of the "source's zone," the total gas consumption in the source Q and the entropy function φ. Moreover, from the incident flow parameters, we determine the quantities p_0, that is, the pressure at the stopping point (the point A in Fig. 1) and p_∞ — the asymptotic value of pressure. Utilizing these quantities, we may find the thermodynamic parameters and the radial velocity in the neighborhood of the sphere r_a, and also the asymptotic values of velocity, density and the cylinder's diameter l, which is approached by the surface β. Knowing the indicated quantities is sufficient to resolve the problem of supersonic flow past the source utilizing the method of the work [3]. But, contrary to [3], we shall have two surfaces sought for (α and β), which should lead to substantial complication of the solution. This is why it is appropriate to subdivide the problem into two parts and consider the inner flow region separately, which will be done subsequently.

The above formulation of the problem refers to flow past a source with known parameters. In case the source is a comet, the quantities φ and are unknown, but we may consider as given the quantities p_0, that is, the density at the point A and l.

The quantities ρ_∞ and v_∞ will be found by utilizing the values ρ_0 and p_0, the latter being exactly equal to the kinetic pressure of the incident flow. The quantity v_∞ will be found from Eq. (1)

$$\bar{v}_\infty^2 = 1 - \frac{2\gamma}{\gamma-1}\bar{p}_\infty^{(\gamma-1)/\gamma}\varphi^{1/\gamma},$$

where

$$\bar{p}_\infty = \frac{\gamma-1}{2\gamma}\frac{p_\infty}{p_0}, \quad \varphi = \frac{\bar{p}}{\rho^\gamma} = \bar{p}_0 = \frac{\gamma-1}{2\gamma}.$$

For the values $\bar{p}_\infty = 0.25\cdot10^{-9}$ $(M=6)$ and $p_0 = \rho_f v_f^2 = 0.72\cdot10^{-8}$ ($v_f = 3\cdot10^7$ cm/sec, $n_f = 5$ cm^{-3}) we shall obtain $\bar{p}_\infty = 0.037\ (\gamma-1)/2\gamma$. At $\gamma=2$ $\bar{p}_\infty = 0.009$, at $\gamma = 1.4$ $\bar{p}_\infty = 0.005$. When substituting these values into the formula for $\bar{v}_\infty$, we shall have: $\bar{v}_\infty = 0.78$ and $\bar{v}_\infty = 0.90$ for the respective values $\gamma = 1.4$ and $\gamma = 2$. From the equality $\bar{p}_\infty / \bar{\rho}_\infty^\gamma = (\gamma-1)/2\gamma$ we shall find: $\rho_\infty = 0.091$ at $\gamma = 1.4$ and $\bar{\rho}_\infty = 0.190$ at $\gamma = 2$.

For the determination of the minimum radius of the source and the flow parameters in the neighborhood of the sphere r_{min}, we shall seek the flow parameters in the neighborhood of a certain sphere of radius r_a, thus finding the condition for which $r_a = r_{min}$. We have three equations: Eq. (1), which we shall write in the form

$$\bar{p}_a = \varphi^{\frac{1}{1-\gamma}}\left(\frac{\gamma-1}{2\gamma}\right)^{\frac{\gamma}{\gamma-1}}(1-\bar{v}_a^2)^{\frac{\gamma}{\gamma-1}}$$

the equation of entropy conservation

$$\varphi = \bar{p}_a / \bar{\rho}_a^\gamma$$

and the equation of flow conservation

$$16\bar{r}_a^2\bar{v}_a\bar{\rho}_a = \bar{v}_\infty\bar{\rho}_\infty,$$

where $\bar{r}_a^2 = r_a^2/l^2$ ($\bar{\rho}_a$, $\bar{v}_a$, $\bar{p}_a$ are respectively the density, velocity and pressure on the sphere r_a Excluding ρ_a and $\bar{p}_a$ from these equations, we shall obtain an equality, linking $\bar{r}_a$ and $\bar{v}_a$

$$\bar{v}_a^{\gamma-1} - \bar{v}_a^{\gamma+1} = \left(\frac{\bar{v}_\infty\bar{\rho}_\infty}{16\bar{r}_a^2}\right)^{\gamma-1}. \qquad (2)$$

The left-hand part of Eq. (2) describes the curve $y = y(\bar{v}_a)$, which for positive v_a has one maximum at $\bar{v}_a^2 = (\gamma-1)/(\gamma+1)$. This is the critical value of the velocity and, consequently, the value r_a corresponding to it equals the minimum radius of the source [2]. This may still be seen from the fact that for smaller r_a Eq. (2) has one root and for greater r_a, it has two roots corresponding to subsonic and supersonic sources.

If the source is supersonic, there must exist at least still one more shook wave enveloping the surface β from within. We consider only a subsonic source of the type apparently analogous to comet nucleus in stationary conditions.

Substituting in (2) the value $\bar{v}_a^2 = (\gamma - 1) / (\gamma + 1)$, we find the minimum radius $r_{min} = 0.13l$ for $\gamma = 1.4$ and $r_{min} = 0.17l$ for $\gamma = 2$. The corresponding values of density and pressure will be (substituting the index m for the index a): $\rho_m = 0.64 \cdot \rho_0$ and $p_m = 0.54 p_0$ for $\gamma = 1.4$; $\rho_m = 0.67 \rho_0$ and $p_m = 0.45 p_0$ for $\gamma = 2$.

All the above said refers to the ionized part of the cometary atmosphere and it is possible to conclude that r_{min} characterizes the minimum dimension of the region where ionization takes place.

The quantity p_0 is determined with a sufficient degree of precision by solar wind pressure and its is not dependent on the comet's "individuality." Starting from this we may estimate p_0. Utilizing the above indicated parameters of the solar wind we shall obtain for the number of cometary ions per unit of volume at the point A:

$$n \sim 0.5 \cdot 10^8 \frac{1}{T_0},$$

where T_0 is the temperature of ions. T_0 should be limited from above: $T_0 < 10^5$, we shall then obtain the lower limit of n_0, which is $n_0 > 0.5 \cdot 10^3$. If lower values of n_0 are observed, it means either that not all the ions are visible [6], or that the shock wave is not forming.

According to the above, the direction of the axis of the type - I tail must coincide with the cometocentric direction of the solar wind velocity. Thus, the deflection of the tail's axis from the radius vector toward the side opposite to comet motion is explained by wind aberration [7].

The existing opinion that the direction of the type-I tail is conditioned by interaction of the tail's plasma with that of the solar wind meets with objections from a number of authors. Thus, in the paper [8], the authors, considering a series of photographs of the Morhaus (1908 III) comet, reach the conclusion that: 1) near the nucleus, the direction of the axis of the tail has already been fixed by ion escape, 2) the surroundings of the nucleus are better protected from the influence of alien ions and 3) the corollary of the first two lead to the conclusion by the authors that solar wind cannot determine the direction of the axis of the tail.

The first stand is well argumented by the authors, and it is difficult not to subscribe to it. The second assertion is also correct provided the "influence" is understood as the "presence."

One may reach the third conclusion by not considering the comet and solar wind plasmas as a continuum and by regarding their interaction as some sort of friction between the cometary ions and electrons with the electrons and ions of the solar wind. But, as already pointed out above, the magnetic field determines the "continuity" of comet and solar wind media, and it is then clear that the ions must escape from the center of the head as if they were "aware" of their trajectory.

The authors express their gratitude to S. A. Kaplan for his guidance in the work and to O. A. Belotserkovskiy for useful consultations.

T H E   E N D

Institute of Radiophysics of the
Gor'kiy State University

Received on 27 November 1965

Contract No. NAS-5-9299
Consultants & Designers, Inc.
Arlington, Virginia

Translated by
ANDRE L. BRICHANT
22-23 August 1966

DISTRIBUTION

GODDARD S. F. C.

100	Clark, Townsend
110	Stroud
400	Bourdeau
601	Fava
610	Meredith
611	McDonald (8)
612	Heppner
	Ness
613	Kupperian
	Hallam
	Bogess III
	Donn
614	White
	Frost
	Behring
	Kastner
615	Bauer
	Goldberg, Herman
	Maier, Stone
640	Hess
	Mead, Nakada
	Cameron, Northrop, Burley
630	GI for SS (3)
252	Library, Freas

NASA HQS.

SS	Newell, Naugle
SG	Mitchell, Smith
	Schardt
	Roman
	Dubin
SC	Liddel
SL	Fellows
	Brunk
	Hipsher
	Horowitz
SM	Foster
	Gill
RR	Kurzweg
RRP	Gessow
RTR	Neill
WX	Sweet

OTHER CENTERS

Ames
Sonett

Langley
160 Adamson
185 Weatherwax

J. P. L.
325 Newburn 183B-365
251 Snyder 180-500
328 Neugebauer 183-401
412 Wyckoff Vis-Lab

U. of Iowa
Van Allen

U. of C. at Berkeley
Wilcox
Field

SWCAS
Johnson

NRL - Friedman

REFERENCES

1. Z. M. IOFFE. Astron. zh., 43, 175, 1966.
2. L. M. MILN-TOMSON. Teoreticheskaya gidgodinamika, "Mir," 1964.
3. O. M. BELOTSERKOVSKIY. Zh. prikl. matem. i mekhan., 24, 511, 1960.
4. P. I. CHUSHKIN, N. P. SHULISHNINA. Tablitsy sverkhzvukovo techeniya okolo zatuplennykh konusov. Vychislitel'nyy tsentr A. N. SSSR, 1961.
5. O. V. DOBROVOL'SKIY. Tr. In-ta astrofiziki A. N. Tadzh. SSR, 8, 1961.
6. L. BIERMANN, E. TREFFTZ. Z. Astrophys., 59, H 1, 1, 1964.
7. P. STUMPFF. Z. Astrophys., 47, 225, 1959.
8. K. WURM, A. MAMMANO. Icarus, 3, N 1, 1, 1964.